REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 31JAN00	3. REPORT TYPE AND DATES COVERED Final Report 15APR99-15JAN00

4. TITLE AND SUBTITLE

Optimal Response Decision Aid (ORDA) for Time Critical Targets: Demonstration Scenario Results

5. FUNDING NUMBERS

Contract #
F30602-99-C-0120

6. AUTHOR(S)

Dr. Joseph H. Discenza

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Daniel H. Wagner Associates, Inc.
2 Eaton St., Suite 500
Hampton, VA 23669

8. PERFORMING ORGANIZATION REPORT NUMBER

Case 7450

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Joe Caroli
Air Force Research Laboratory/IFTB
525 Brooks Rd., Bldg. 3
Rome, NY 13441-4054

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT (see Section 5.3b of this solicitation)

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Report developed under SBIR contract for topic AF99-117. U.S. forces need to use intelligence in a timely and efficient manner to protect against mobile ballistic missile launchers and other time-critical threats. This research, using off-the-shelf software developed for other services, showed how the Air Force could use a scientific search planning decision aid to allocate surveillance assets optimally.

14. SUBJECT TERMS

SBIR Report, Search Planning, SCUD Search, Monte Carlo

15. NUMBER OF PAGES 25

16. PRICE CODE

17. SECURITY CLASSIFICTION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

Standard form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

REF E

DTIC QUALITY INSPECTED 1

Optimal Response
Decision Aid (ORDA)
for Time Critical Targets:
Demonstration Scenario Results

Final Report
SBIR Phase I Contract

Contract Number F30602-99-C-0120

January 31, 2000

Prepared for

Tech. Rep. Joe Caroli
AFRL/IFTB
Rome NY
315-330-4205

By

Dr. Joseph H. Discenza
Daniel H. Wagner Associates, Inc.
2 Eaton Street, Suite 500
Hampton, Virginia 23669
(757) 727-7700

ABSTRACT

One of the lessons learned from the anti-SCUD effort in the Gulf War is the need for efficient and timely use of intelligence in a decision support system to increase the chance of success of detecting and destroying missile threats *prior to launch*. Ballistic missile launchers are specific examples but other threats, such as cruise missiles, air breathing threats, tactical air to surface missiles, and ground/air support equipment together fall under the definition of "Time Critical Targets" or TCTs. An ideal system would have many desirable qualities. It would operate quickly on standard off-the-shelf computers; it would utilize all information, both positive and negative concerning the targets of interest; and it would provide optimal search plans that maximize success probability in strike operations. To be maximally useful the system would also interface directly with command and control networks for fast receipt and dissemination of real-time surveillance information. The purpose of the Phase I was to examine the feasibility of building such a decision support system with off-the-shelf components.

Our overall objective in this proposed SBIR program is to have a working decision support module for TCT prosecution installed in an AOC and ready for widespread fielding. In order for the Phase II to be successful, the following Phase I objective were met:

Objective 1. To define the key components of a successful decision aid for Air Force prosecution of time-critical targets;

Objective 2. To determine how such a decision aid can be successfully integrated in an Air Operations Center, considering present environment and ongoing developments;

Objective 3. To demonstrate the utility of such a decision aid using existing, off-the-shelf software;

Objective 4. To develop a scope of work and plan to create and field a successful TCT decision aid within the resources and time constraints of a Phase II SBIR program;

Objective 5. To determine the additional decision support tools that could be added in a Phase III program.

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1. DEMONSTRATION

1.1. Methodology

The Phase I demonstration was accomplished using existing software, called SSPS, developed for U.S. Navy applications in undersea warfare and later extended to model surface, air, and ground moving targets. In the following graphics we show actual output from SSPS, using its new ground target modeling feature. This example was designed to show how the system would perform in a real TCT search and targeting situation. In this example, the target is detected at a particular location and figure 1(a) shows the uncertainty associate with this direction. The primary motion assigned to this target is that it is about to move to a new hiding place. In this case, we have set up four different escape routes. At any time in the scenario, SSPS can produce a display of the probability distribution of the target by a probability map, as shown in Figure 1.

The underlying methodology in SSPS is Monte Carlo simulation, wherein large numbers of possible target sample paths are created to represent the overall probability distribution in time and space. These replications are modified by the system to account for positive (contact) information and negative (unsuccessful surveillance) information.
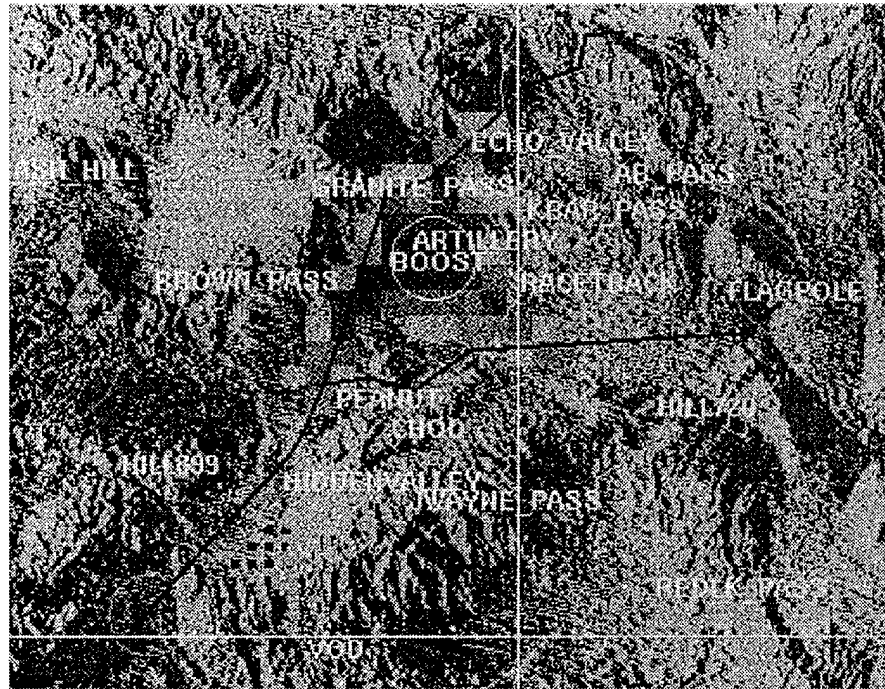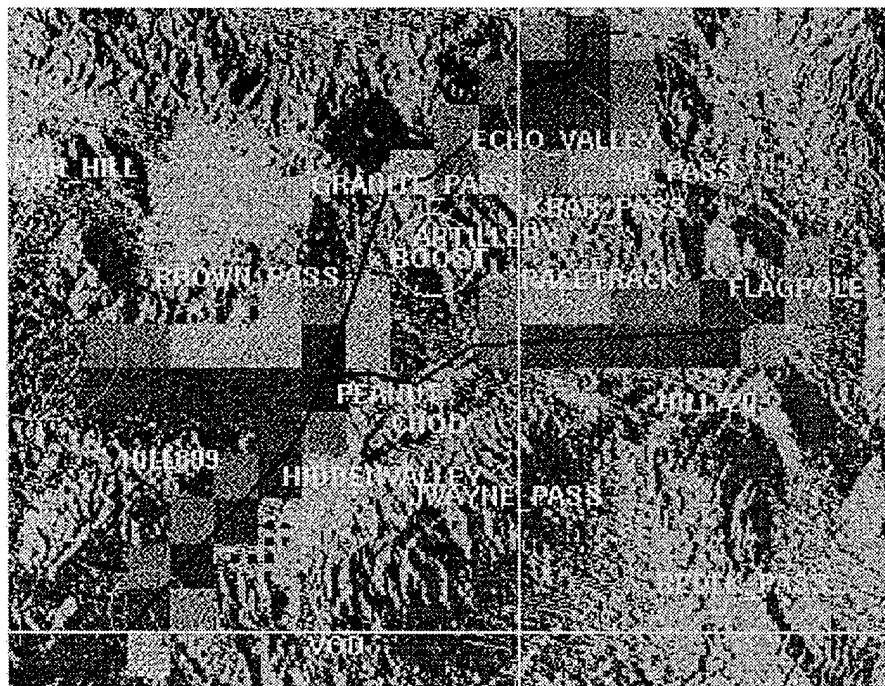
Figure 1. Probability Maps for Evading Time Critical Target, (a) just after a detection report and (b) an interval of time later. Dark regions represent areas of high probability. Actual computer displays utilize different color scales and shades.

In order for the SSPS to model the target and produce these probability maps, it needs:

- Accurate models for the errors in location reports; we used unclassified estimates for these values.

- Realistic models for target motion; we used existing target motion models installed for our previous USN sponsor.

- Accurate models for the assets' abilities to detect the targets of interest; we made reasonable unclassified estimates based on data from open sources.

- Adequate environmental models and databases: terrain and features for target motion and visibility plus atmospherics for transmission loss; we used an existing terrain and feature database in the Fort Irwin area created under a previous program for an SMDC sponsor.

The SSPS models target motion as follows. Each sample Monte Carlo target starts at a point selected at random from an initial probability distribution entered by the user. The target then folows a sequence of motion "legs" selected from a distribution specified in the motion model for that target. Two types of motion leg may be used for a ground target in the present program. The first follows a totally random motion pattern with a course and speed distribution. The second has a precise destination chosen at random from an elliptical "goal." In the gola type leg, the sample finds the best path and follows it to the destination, at speeds chosen at random from a distribution.

We modeled a target in hiding with a nearly stationary random motion contained within a defined no-detection polygon. We entered a number of these polygons as "known" or "suspected" hiding places.

In order to validate the utility of search planning techniques and as part of our Phase I performance, we developed a comprehensive demonstration scenario and used SSPS to obtain example planning results. As the premise for our scenario[1], Red country, with its capital at Barstow CA and southern boundary at latitude 34N, has invaded and captured its southern neighbor SOCAL, a nation friendly to the West. Red's lone SCUD battalion operates in the remote region of the National Training Center, with a Forward Operating Base at an unknown location near Fort Irwin. The threat units are shown in the following table:

1 SCUD Battalion
3 Launch Batteries
Each Battery:
        3 launch vehicles
        2 decoys
        2 command & control vehicles
Forward Operations Base
        3 single transporters
        4 triple transporters
        6 mobile cranes
        12 fuel trucks
        5 oxidizer vehicles
        3 checkout vans
        6 command & control vehicles

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[1] This scenario was developed with the assistance of staff at the Air Forces Joint Tactical Attack Analysis Center.

In this early entry scenario, Blue forces have captured San Clemente Island and Catalina Island and are marshaling forces for a landing at Camp Pendleton. The Patriot anti-missile battery ordered into Catalina Island has not arrived.

1.2. Red Strategy

Red operates relatively freely, because of Blue's limited reconnaissance capability. Each battery operates as a unit, hiding most of the time and appearing only for re-supply and launch. Launches are randomly spaced in time and each TEL gets about one launch per day. The targets are Blue forces on the two islands and Red's objectives are to harass Blue during its preparation phase, obtain worldwide news coverage, destroy munitions and other supplies, kill Blue personnel, and divert Blue resources.

Blue forces began arriving two days ago. The Air Force ACC command center at Langley AFB is coordinating TCT collection and targeting.

SCUD attacks have now been underway for 24 hours. Six missiles have landed harmlessly in the water or on deserted areas on Catalina Island, two have damaged civilian residential areas killing 12 noncombatants, and one has struck and destroyed a fuel storage area near the temporary landing strip.

Blue intelligence reports that Red has a small stockpile of Sarin nerve agent and believes that a limited number of SCUD warheads are equipped to deliver the gas. Blue intelligence assesses that Red is willing to use non-conventional warheads but intends to save them for a coordinated strike when Blue forces are amassed in greater numbers, perhaps at the height of the amphibious landing operations.

1.3. Blue Strategy

The Blue commander has ordered that all efforts be made to reduce or eliminate Red's SCUD launch capability prior to the commencement of amphibious operations. He has made available one PREDATOR UAV system for surveillance and has requested that a limited number of satellite image passes be made available.

The PREDATOR incorporates electro-optic, infrared, and synthetic aperture radar sensors, and transmits imagery in real time to its ground control station. It was designed for a 500-nautical mile radius and endurance in excess of 24 hours on-station, while operating at altitudes from 15,000 to 25,000 feet.

The scenario assumes that the PREDATOR operates as follows. Upon launch, it transits to the AOI, approximately 2.5 hours at cruise speed. It then searches at a speed of 20 knots, using its sensors to cover an area of approximately 3 km on either side of its path[2]. After 8 hours on station, covering one or more assigned search rectangles, the UAV will be relieved by a second bird and will return to base. Insofar as maintenance, weather, and operability allow, the three birds will provide one continuous asset in the AOI.

The UAV operation has been ongoing since the first SCUD launch was detected and several detections have been recorded. Also, two satellite detections of suspected battalion resources have been reported. National resources have reported the positions of all of the launches. Blue has a list of known or suspected hides and has an estimate of the Ops Tempo of the enemy force.

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[2] In search theory terms, we used a sweep width of 6 km.

1.4. Search Planning Demonstration

We used the Decision support System Testbed to simulate the activities of the nine launchers and six decoys during the first 24-hour period. We also simulated the searches of the three predators, using arbitrarily constructed search patterns. We simulated the detection by overhead sensors of one launch each from the nine launchers. When the scenario was run, the UAV sensors detected actual launchers, decoys, and false targets, and the simulated overhead sensor detected the launches themselves. All of these reports were automatically fed to the Near Real Time Data Fusion (NRTDF) system, which used a new target model for each launch vehicle at the time of its launch. Once the new target models were initialized, then NRTDF attempted to correlate subsequent UAV reports to those tracks.

We created a common tactical motion model for the nine launchers and assigned the model to nine different target models in the SSPS program. We used the reports from the first 24 hours to create and modify target models and movements for the second 24 hours. We used the SSPS program to create optimal search areas for the UAV assets for the second 24-hour period.

1.5. Scenario Simulation

The DSST represents scenarios as collections of platforms, with assigned detectabilities, sensors, and events. We modeled the 9 launchers, 6 decoys, 3 UAVs, and a single overhead launch detector as individual platforms. We assigned the UAVs arbitrary search areas in successive 8-hour periods, with tracks spaced 6km apart. One UAV searched on East-West legs, one on North-South legs, and one in NE/SW orientation. We named the launchers for their Battery and Launcher Number (e.g., B1L1) and assigned launch locations and times, as shown in Table 1.

Table 1. Missile Launch Times and Locations

Launcher	Time of Launch	Latitude			Longitude		
B1L1	010228Z	35	24	39N	116	34	14W
B2L1	010500Z	35	14	24N	116	43	00W
B3L1	010654Z	35	21	01N	116	34	36W
B3L2	010848Z	35	22	40N	116	23	07W
B1L2	011218Z	35	14	26N	116	42	02W
B2L2	011533Z	35	27	42N	116	30	37W
B3L3	011656Z	35	22	23N	116	25	08W
B1L3	011943Z	35	15	25N	116	39	52W
B2L3	012106Z	35	21	26N	116	35	37W
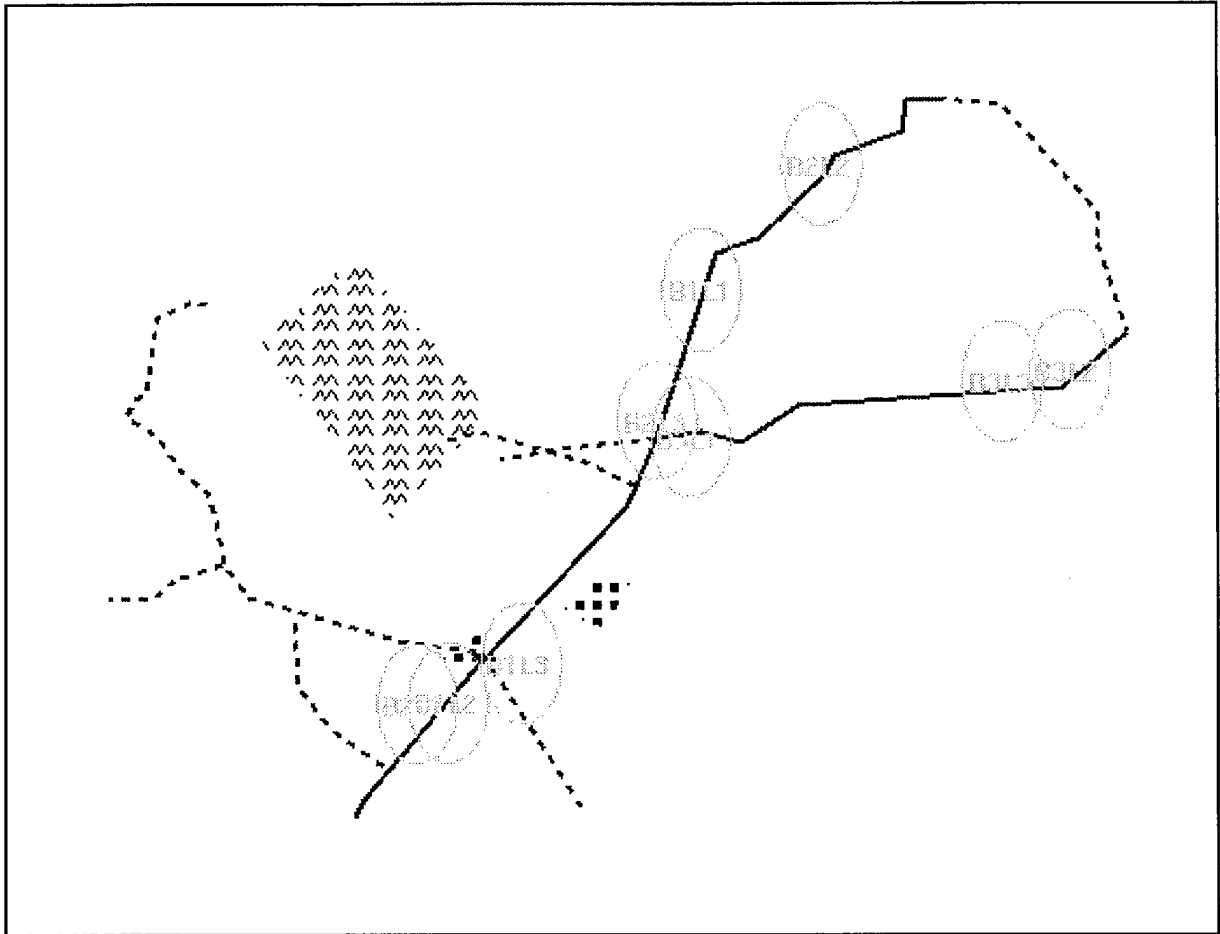
Figure 2.   Nine Launch Detections Recorded

Each launcher was then assigned an initial location at one of the hides.   After initialization, the launcher was either given a movement to a re-supply point or to the launch site at 30 km/hr. For a re-supply, the launcher was given a delay for an hour or less and then directed to another hide location at 30 km/hr.   At the launch point, the launcher was then given a stop maneuver for 30-45 minutes and then another maneuver at 60 km/hr toward a quick-hide location.   The launcher then stayed at the quick hide for a limited time period, between 1 and 4 hours.   The quick-hide locations, which are known to the Search Planning program, are shown in Table 2. Re-supply locations are unknown to the Search Planning Program.

Table 2. Quick Hiding Locations

Quick Hide	Latitude			Longitude		
QUIK11	35	26	58N	116	19	19W
QUIK12	35	20	12N	116	24	25W
QUIK13	35	24	53N	116	17	37W
QUIK21	35	29	44N	116	25	56W
QUIK22	35	29	25N	116	23	22W
QUIK31	35	12	38N	116	42	48W
QUIK32	35	15	35N	116	41	03W
QUIK33	35	13	18N	116	43	26W
QUIK34	35	17	43N	116	36	36W

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After the quick hide period, the launcher was given a different hide location and a maneuver to get it to that location. The other hide locations[3], also known to the Search Planning program, are shown in Table 3.

Table 3. Other Hiding Locations

Hide	Latitude			Longitude		
HIDE 01	35	16	48N	116	16	09W
HIDE 02	35	27	59N	116	15	36W
HIDE 03	35	14	45N	116	23	05W
HIDE 05	35	28	00N	116	44	14W
HIDE 06	35	15	15N	116	23	50W
HIDE 09	35	26	36N	116	43	54W
HIDE 10	35	7	42N	116	41	42W
HIDE 12	35	24	33N	116	53	15W
HIDE 13	35	13	24N	116	23	43W
HIDE 14	35	14	43N	116	26	12W
HIDE 15	35	22	42N	116	16	09W
HIDE 16	35	13	56N	116	29	50W
HIDE 20	35	7	47N	116	36	38W
HIDE 21	35	13	41N	116	21	26W
HIDE 23	35	7	42N	116	22	49W
HIDE 24	35	8	59N	116	32	34W
HIDE 26	35	12	46N	116	48	33W
HIDE 27	35	19	15N	116	16	01W
HIDE 29	35	16	21N	116	45	38W
HIDE 30	35	10	10N	116	48	27W
HIDE 31	35	20	45N	116	43	30W
HIDE 32	35	10	19N	116	36	43W
HIDE 34	35	26	39N	116	48	53W
HIDE 36	35	9	20N	116	53	20W
HIDE 37	35	13	27N	116	24	47W
HIDE 38	35	9	23N	116	18	35W
HIDE 39	35	12	08N	116	27	10W
HIDE 40	35	16	22N	116	53	09W

For launches that occur earlier in the day, after the hide period of 6-8 hours the launcher was given a re-supply location and a maneuver to get to that location at 30 km/hr. Again, after arriving at the re-supply point, the launcher experienced a delay time, after which it was given a maneuver to transit to a different hide location.

We modeled the collection assets in the DSST as moving platforms. The UAV searchers were given parallel tracks at 6km spacing as discussed above. To facilitate the representation of the "hiding" activities of the TELs (including the decoys), we assigned each TEL a simulated IFF transponder that we then turned on and off, representing alternating periods of hidden and

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[3] Gaps in the numbering sequence are the result of culling locations from a randomly generated list. Nine were removed to be quick hides (listed above) and 3 were removed because they overlapped others too closely for adequate modeling.

non-hidden activity.[4] We equipped the UAV platforms with IFF interrogators with a maximum range of 3 km, to allow them to detect the TELs. To produce the launch detections, we created a "satellite" platform with a simulated short-range radar sensor that we turned only for a few seconds at the time of each launch. Then by making sure the platform was near the correct TEL at those launch times, the radar would report The launches.

After setting up all the platforms, motions, and sensors, we then ran the DSST to see what would happen. Not surprisingly, even with constant UAV presence and with fifteen targets moving around the area, only four detections were reported, all of them concentrated over a few hours in the middle of the 24-hour period.
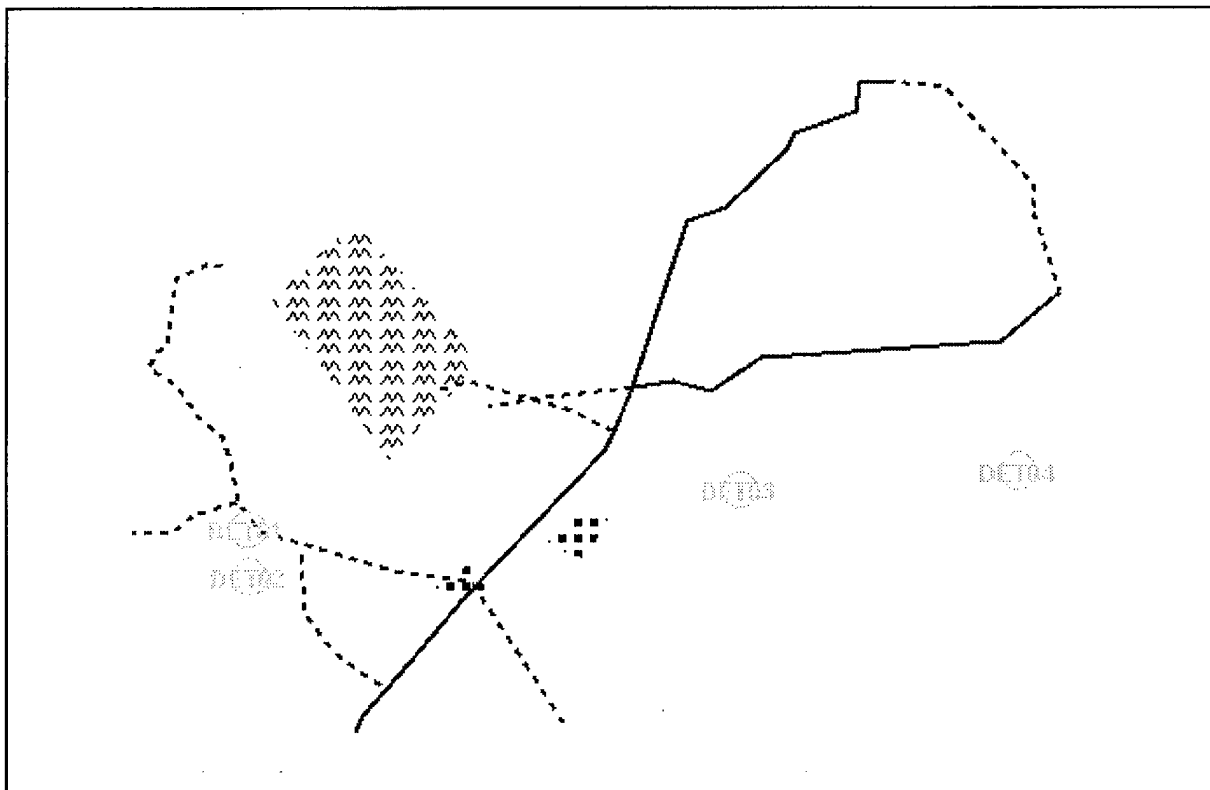
Figure 3. Four UAV Detections of Suspected Launchers During Day 1

1.6. Search Modeling

We used the SSPS program to create a search model for the demonstration TCT scenario. An SSPS target model consists of one or more position reports, a set of motion models, and optionally one or more unsuccessful searches. The system creates a set of initial points using draws from the earliest position report. It then selects initial motion legs from the assigned model and begins building sample paths. Once all the sample paths have been constructed, SSPS then applies the other contact reports (positive information) and searches (negative information) to modify path weights[5].

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[4] The present DSST does not have a built-in capability for a non-cooperative target to become hidden from detection.

[5] Subsequent contact reports or searches may reduce the weights of many sample paths to near zero. If the proportion of these paths becomes too large, the Monte Carlo model is inefficient. In such cases, SSPS automatically regenerates all the replications. This did not happen in our demonstration scenario.

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SSPS has a large library of motion leg types, two of which are useful for modeling motion in terrain. The primary motion leg type is "motion toward elliptical goal." This means that a sample path chooses a destination at random from a bivariate normal probability distribution and then moves itself toward that destination in the best way possible. In this type of motion, the target is assumed to know its destination and all the terrain on the way.

The second motion leg type we use is called "unconstrained patrol motion." This means that the sample paths choose a course and speed from a distribution, move for a while, then choose a new course and speed. We use this leg type as a loiter motion, with very low speed, to keep targets stationary during launch, re-supply, and hiding activities[6].

A complete detailed motion model consists of a collection of motion legs and transitions from one to the next, the transitions being controlled by arrival events or by time delay selected from a distribution. In the demonstration scenario we represented launch and re-supply locations as large elliptical position goals and hiding locations as very small position goals. The demonstration model transitions to patrol motion upon arrival at a position goal, then transitions to another position goal after an appropriate delay time.

This motion scheme represents movements from hiding locations to re-supply/launch/other hiding locations, in accordance with the tactics described in section 1, above. Figure 4 shows the complete detailed motion model with legs and transitions. Ellipses represent geographic goal motion legs, rectangles represent patrol motion (activity in one location for a time period), and arrows represent transitions.

Motion legs "LAUNCH0x" are large ellipse goals representing unknown launch locations. We chose these three ellipses along the three major roads in the area, using the intelligence about the Red strategy to move at high speed (meaning major road) to a hiding place immediately after a launch. Similarly "SUPLLY0x" are large ellipse goals representing re-supply locations.

Motion legs "SETUP0x" are delay legs, one for each launch. These allow the target to transition to a nearby quick hide location after a launch. Motion legs "QUIKxy" are the quick hiding destinations for LAUNCH0x, from Table 2.

Motion leg "SHORTHIDE" provides the delay time for the first hiding destination after a launch. Motion legs "HIDEnn" are the other hiding locations from Table 3. Finally, motion leg "LONGHIDE" represents a long delay before either re-supply or launch. To limit the complexity of this demonstration, we did not distinguish between hiding before re-supply and hiding before launch. Thus any sample path coming out of a long hiding is equally likely to proceed to a re-supply point as to a launch point.

We created nine TCT search targets, each one beginning with a confirmed launch position and time as listed in Table 1, above. We named these targets, "LAUN01," LAUN02," etc. We assigned a starting motion leg SETUP0x depending on the location of the actual launch detection.

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[6] SSPS does not have a "stopped" motion leg type.
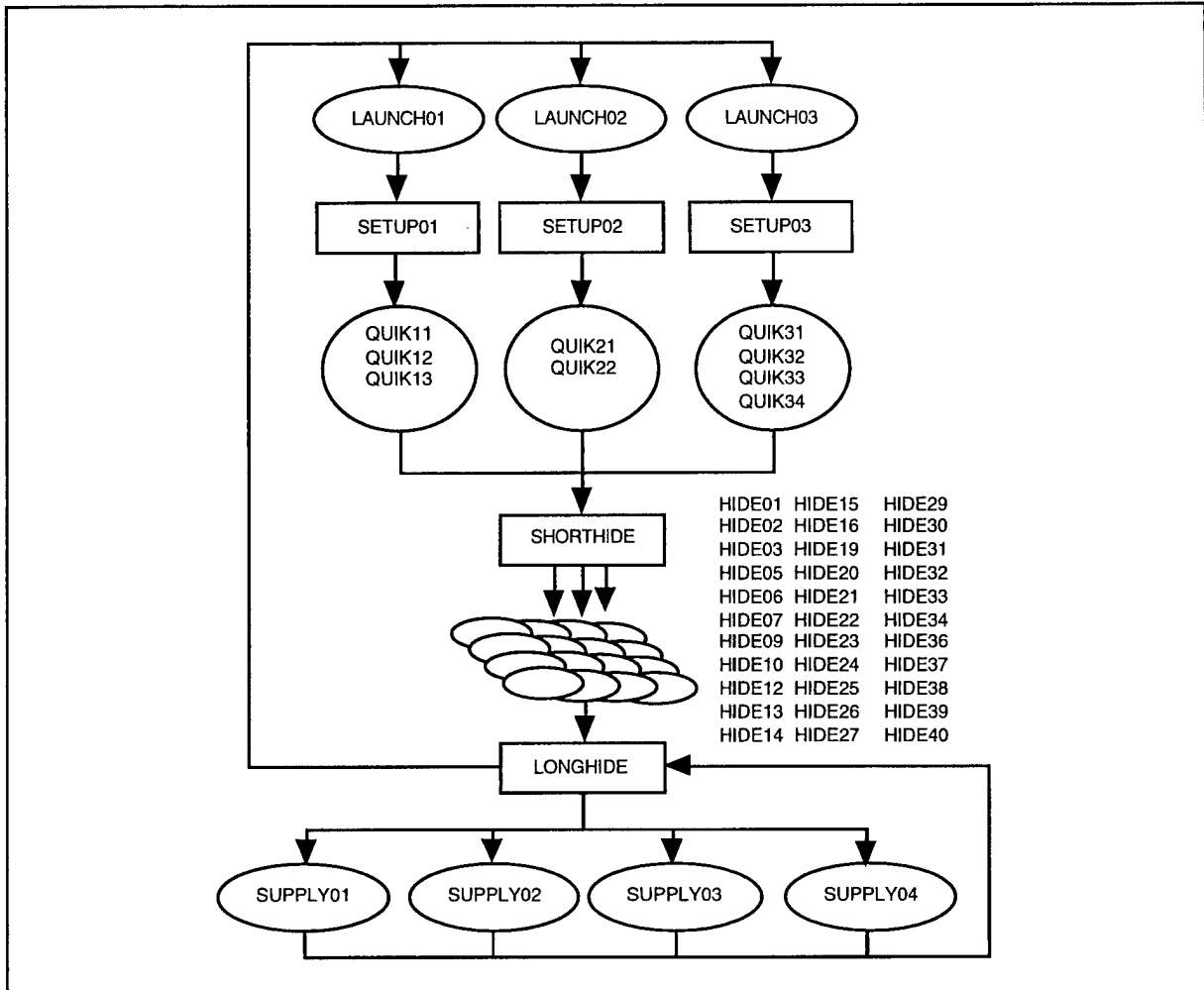
Figure 4. SSPS Motion Models and Transitions for Time Critical Targets (launchers)

We then entered each of the UAV contact reports, using appropriate confidence and error probability ellipses based on report sources. We assigned each report to a specific prior launch observation, as a fusion operator might do in real life. The actual contact reports generated by the data generator are given in Table 4[7].

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[7] The column labeled "Target" indicates the actual target that generated the UAV detection. The column labeled "Others" indicate other nearby targets that might have been confused in the correlation process. Note that correct correlation would have been very difficult for these detections. For instance, detection DET01 was actually generated by target B1L3 before its launch and DET02 was generated by B2D2 (a decoy). Both of these detections could only be correlated (incorrectly) with B2L3 (LAUN02). DET03 could only be correlated with B3L1 (the correct target). DET04 could be correlated with B1L1 (the correct target) and B3L2. We assigned a weight of 1/12 for the single correlations, since Blue knows that there are a total of 15 potential targets, only four of which have been confirmed (by missile launch). Therefore, a detection could be the selected launch *or any of the other 12 undetected targets.* A similar argument results in a confidence of 1/13 for DET04.

**Table 4.** UAV Detection Reports and Target Assignments

Detection	Target	Others	DTG	Latitude	Longitude	Assign to	Confidence
DET01	B1L3	B2D2 B2L3	010935	3517.1	11649	LAUN02	0.0833
DET02	B2D2	B1L3 B2L3	010948	3515.8	11648	LAUN02	0.0833
DET03	B3L1		011020	3518.2	11632	LAUN03	0.0833
DET04	B1L1	B3L2	011123	3518.7	11623	LAUN01 LAUN04	0.0769 0.0769

We entered these contact reports to the assigned targets and each of the three UAV searches as negative information for all targets. We then generated moving probability maps for each battery, from the time of launch to the end of the upcoming 24-hour collection period. Finally, we combined all nine launcher targets into a single scene and entered the UAV launch and recovery details.

The scenario specifies three UAVs searching on Day 2. Other versions of our search optimizer can automatically create multiple search areas in one sortie but the present SSPS implementation does not support this feature. In order to provide a more flexible search strategy, we split each of the 8-hour sorties in two, resulting in a total of six separate sorties. For each UAV we specified a geographic position on scene as the recovery position of the first sortie and the launch position for the second, as though the UAV were to land and take off again immediately. This achieved the required timing for the six sorties.

SSPS has a feature that allows the search planner to specify exclusion zones in which the searcher may not fly. This feature is used operationally for territorial boundaries, restricted areas, or other no-fly zones. The optimizer does not actually create routes that avoid these areas but just gives a zero probability of detection for any sample path included. To handle the hide zones in this demonstration scenario, we implemented a new elliptical exclusion zone type and then created one for each of the hiding places in the scenario. Thus, the optimizer will not look for sample paths when they are in hiding (inside these zones). Figure 5 shows these zones plotted on the scenario map and named according to Tables 2 and 3.

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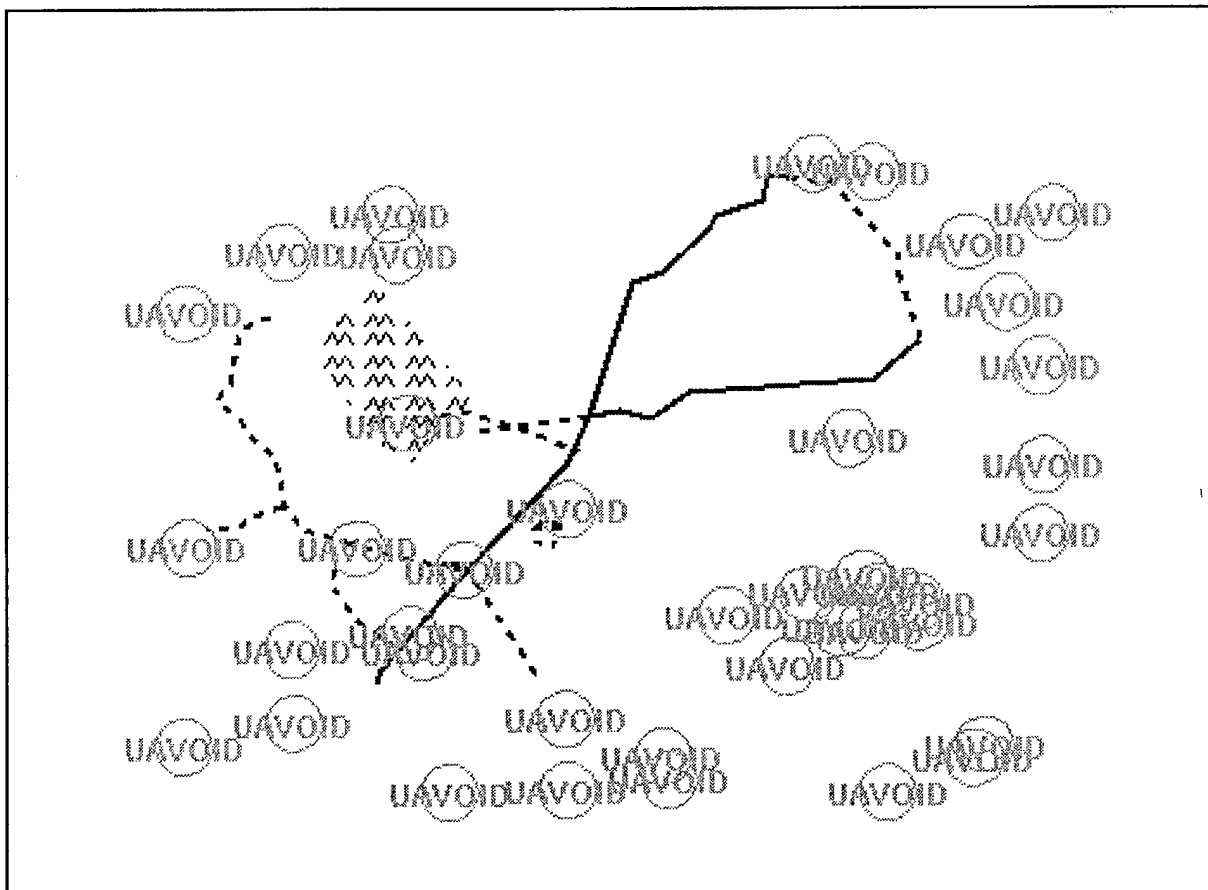
Figure 5. Search Exclusion Zones Representing TCT Hiding Locations

1.7. Scenario Results

The following figures show the results of the search planning calculations for this scenario, using SSPS outputs. The first set of images in Figure 6 show a sequence of probability maps from target "LAUN02," which has not only the negative information but two location reports.

Notice that the probability begins at the reported launch position and then moves toward the quick-hide positions and then to longer-term hiding positions. After several hours, the probability begins to spread out as the target model moves to re-supply and then back into hiding. In all of these probability maps, the target probability is displayed, whether or not the target is in hiding or not.

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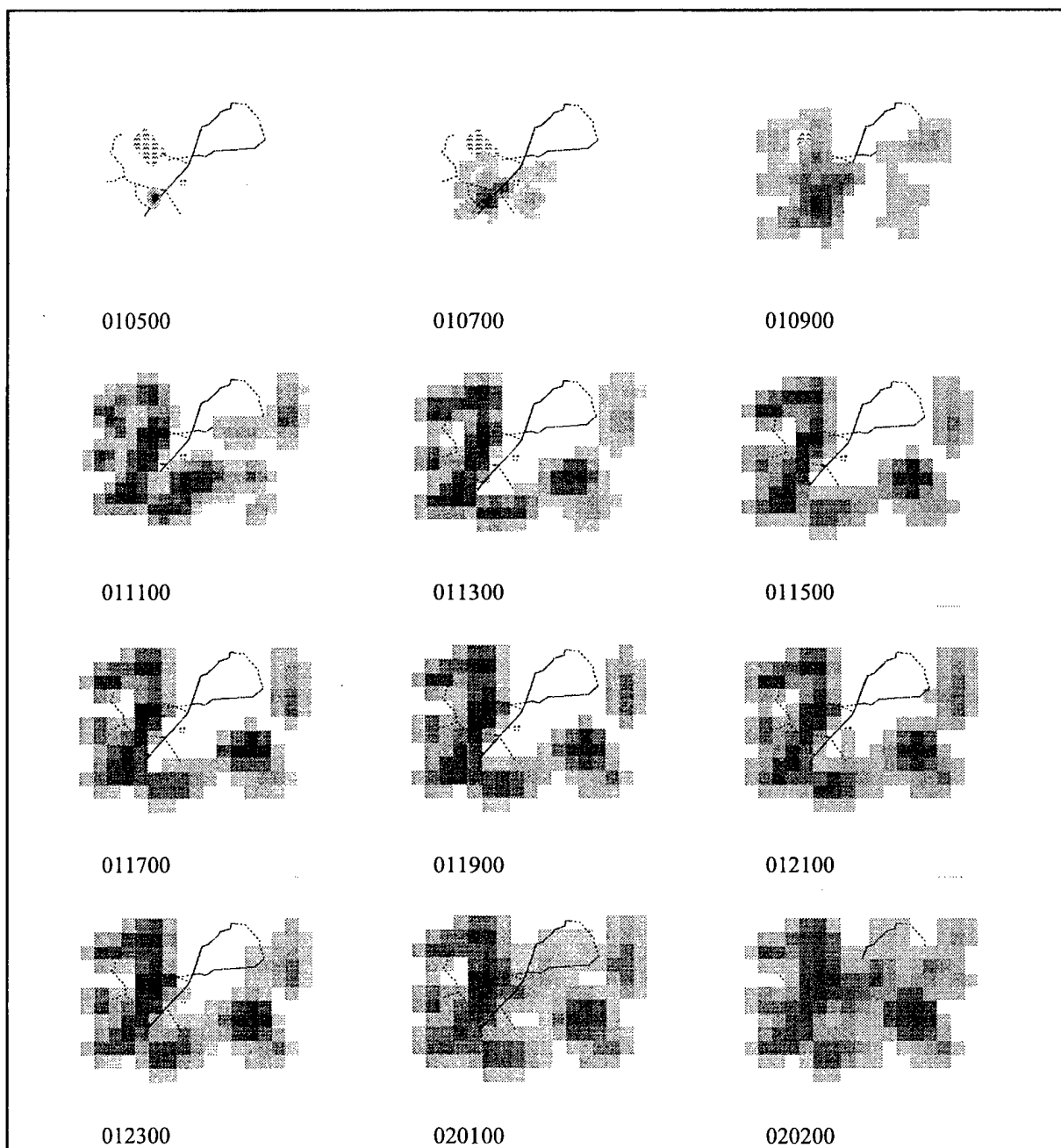
Figure 6. Probability Sequence for Target LAUN02

The next sequence shows combined probability for all nine targets in the scene, for the second 24-hour period.
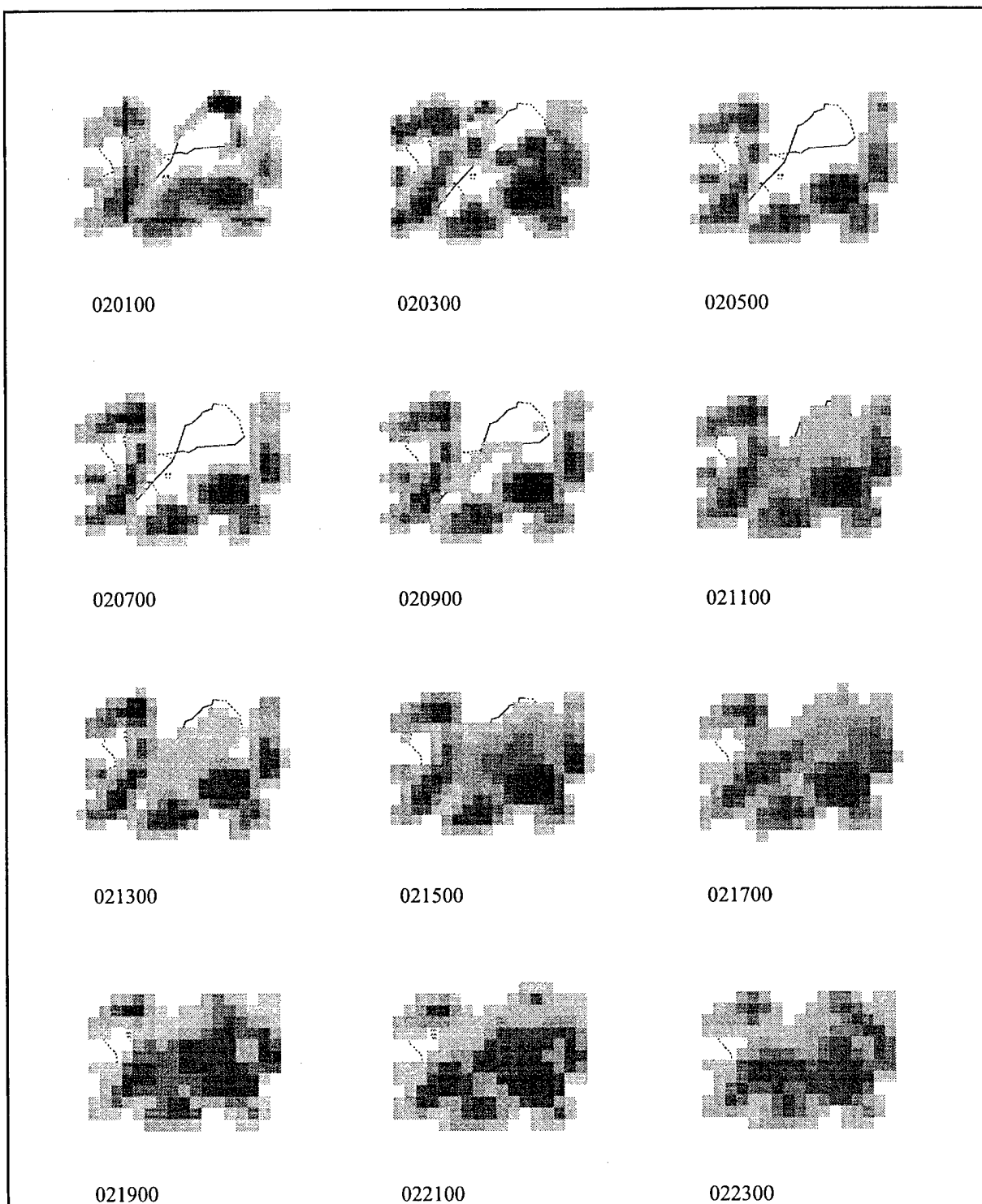
Figure 7. Probability Sequence for Scene TCTSCENE

Finally, the optimizer produced six search rectangle assignments for the three UAVs, as shown in Figure 8. The data for the optimized searches are given below.

```
>  UAV1A  012130Z JAN98 020400Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3330N  LAUNCH LON: 11827W
      RECOVER LAT: 3519N  RECOVER LON: 11708W  MAX # OF RECTS: 1
>  UAV1B  020415Z JAN98 021030Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3530N  LAUNCH LON: 11700W
      RECOVER LAT: 3324N  RECOVER LON: 11808W  MAX # OF RECTS: 1
>  UAV2A  020530Z JAN98 021200Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3325N  LAUNCH LON: 11825W
      RECOVER LAT: 3530N  RECOVER LON: 11700W  MAX # OF RECTS: 1
>  UAV2B  021200Z JAN98 021830Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3530N  LAUNCH LON: 11700W
      RECOVER LAT: 3325N  RECOVER LON: 11830W  MAX # OF RECTS: 1
>  UAV3A  021330Z JAN98 022030Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3325N  LAUNCH LON: 11830W
      RECOVER LAT: 3530N  RECOVER LON: 11700W  MAX # OF RECTS: 1
>  UAV3B  022000Z JAN98 030230Z JAN98 RPV            3      60     20   10000
      SENSOR: RADAR   BASE: MANUAL    LAUNCH LAT: 3530N  LAUNCH LON: 11700W
      RECOVER LAT: 3325N  RECOVER LON: 11830W  MAX # OF RECTS: 1
MOE : MAXIMIZE PROBABILITY OF DETECTION        **
OPTIMIZATION CONSTRAINT : NONE **
DO NOT DECONFLICT SEARCHES **
DO NOT USE AVOIDANCE AREAS **
SORTIE GROUPINGS DEFINED : NONE  **



   BEST SEARCH FOR UAV1A  IS 1 RECTANGLE(S) STARTING AT 012130Z JAN98
   --- RECTANGLE #1 ---
     START SEARCH TIME :  012345Z JAN98
     END SEARCH TIME   :  020336Z JAN98
     CENTER LATITUDE  : 3519N
     CENTER LONGITUDE : 11633W
     LENGTH :   20.0 NM
     WIDTH  :   15.0 NM
     BEARING :  94 DEG
   CUMULATIVE PD THROUGH THIS EVENT IS 0.34
      **
   BEST SEARCH FOR UAV1B  IS 1 RECTANGLE(S) STARTING AT 020415Z JAN98
   --- RECTANGLE #1 ---
     START SEARCH TIME :  020447Z JAN98
     END SEARCH TIME   :  020817Z JAN98
     CENTER LATITUDE  : 3519N
     CENTER LONGITUDE : 11621W
     LENGTH :   25.0 NM
     WIDTH  :   11.0 NM
     BEARING :  22 DEG
   CUMULATIVE PD THROUGH THIS EVENT IS 0.50
      **
```

BEST SEARCH FOR UAV2A IS 1 RECTANGLE(S) STARTING AT 020530Z JAN98
--- RECTANGLE #1 ---
  START SEARCH TIME : 020741Z JAN98
  END SEARCH TIME   : 021139Z JAN98
  CENTER LATITUDE : 3518N
  CENTER LONGITUDE : 11645W
  LENGTH :   21.0 NM
  WIDTH :   14.0 NM
  BEARING : 13 DEG
CUMULATIVE PD THROUGH THIS EVENT IS 0.63
    **
BEST SEARCH FOR UAV2B IS 1 RECTANGLE(S) STARTING AT 021200Z JAN98
--- RECTANGLE #1 ---
  START SEARCH TIME : 021219Z JAN98
  END SEARCH TIME   : 021608Z JAN98
  CENTER LATITUDE : 3518N
  CENTER LONGITUDE : 11628W
  LENGTH :   20.0 NM
  WIDTH :   15.0 NM
  BEARING : 76 DEG
CUMULATIVE PD THROUGH THIS EVENT IS 0.75
    **

BEST SEARCH FOR UAV3A IS 1 RECTANGLE(S) STARTING AT 021330Z JAN98
--- RECTANGLE #1 ---
  START SEARCH TIME : 021543Z JAN98
  END SEARCH TIME   : 022021Z JAN98
  CENTER LATITUDE : 3517N
  CENTER LONGITUDE : 11639W
  LENGTH :   24.0 NM
  WIDTH :   20.0 NM
  BEARING : 96 DEG
CUMULATIVE PD THROUGH THIS EVENT IS 0.83
    **
BEST SEARCH FOR UAV3B IS 1 RECTANGLE(S) STARTING AT 022000Z JAN98
--- RECTANGLE #1 ---
  START SEARCH TIME : 022033Z JAN98
  END SEARCH TIME   : 030014Z JAN98
  CENTER LATITUDE : 3516N
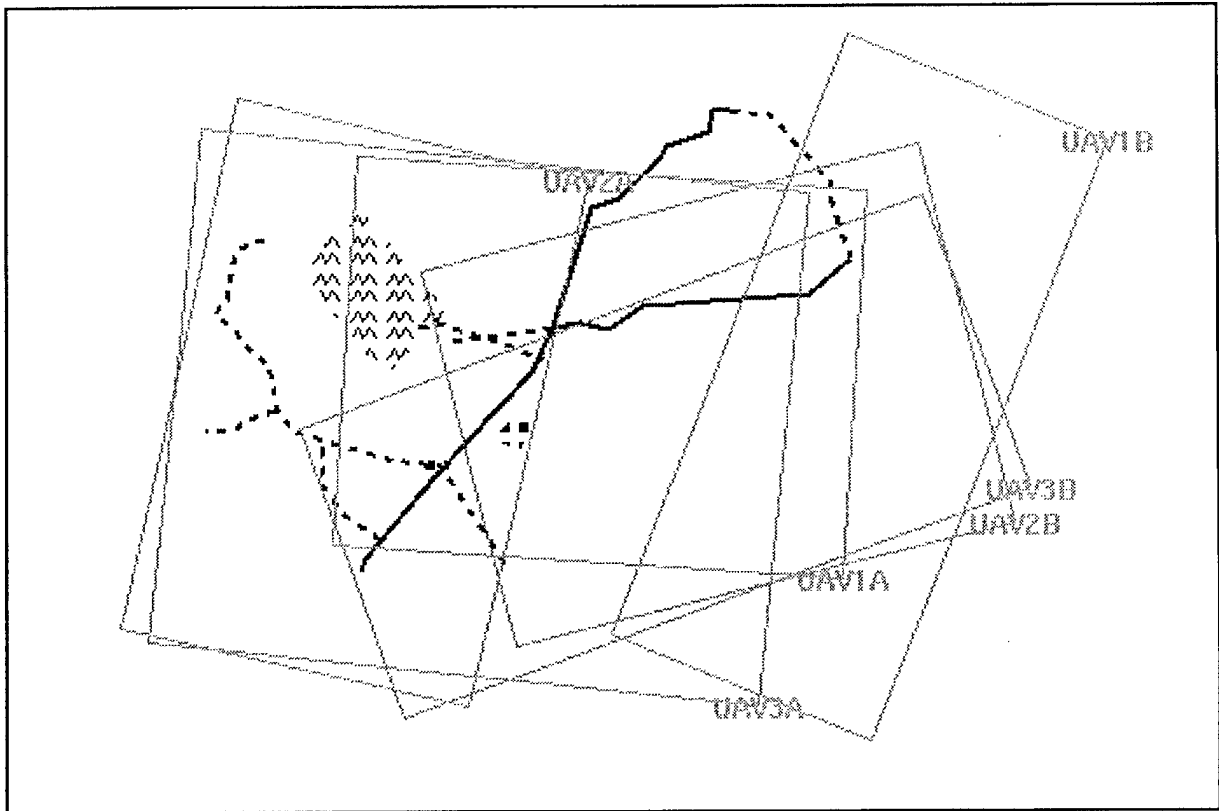 CENTER LONGITUDE : 11630W
  LENGTH :   26.0 NM
  WIDTH :   12.0 NM
  BEARING : 70 DEG
CUMULATIVE PD THROUGH THIS EVENT IS 0.88
    **
CUMULATIVE PD FOR RECOMMENDED PLAN IS 0.88

Figure 8. Search Areas for the UAVs in Day 2, as computed by the optimizer

This is a complete set of search area objectives for the three UAVs to be used on the second day, representing a complete collection plan for these assets. If other types of assets were also available, we could either add them in to the optimization mix and re-compute a new collection plan (the best way) or we could insert these UAV plans into the Monte Carlo model as negative information and then compute the new asset plans separately.

This demonstration scenario then illustrates all the capabilities needed for TCTDSS: modeling of time critical targets with realistic motion models; correlating target reports with the models; incorporating both positive and negative information into the planning models; and computing recommended collection plans for available assets.

1.8. Sensor to Shooter Demonstration

The most effective potential means of dealing with mobile targets is to apply a weapon directly based on near real time sensor reporting. Notwithstanding the difficulty of building and operating sensor networks that can deliver sensor reports with minimum delay, there are new weapons being developed that can react rapidly to sensor reports with highly effective fire. The following demonstration, based on the same underlying tactical model as the first simulation, uses the boost phase sensor report to provide cueing to a single Low Cost Autonomous Attack System (LOCAAS), being developed by Lockheed Martin Company.

This weapon is a flying smart bomb that can be programmed to search out an area and then to attack a target that matches a threat profile, using Automatic Target Recognition (ATR). The weapon flies at 215 knots and searches at an altitude of 750 feet, covering a small swath of about 150 feet at that altitude with a LADAR sensor. The weapon can be used in raids because

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they can share detection and targeting data via radio while in the search mode. The weapon can detect multiple targets and then decide at the end of its search which one to attack.

We simulated the use of this weapon to react to boost phase launch reports of the TELs in the previous example. Since the weapon can only fly for about 28 minutes, we stationed the launch platform at approximately 45 NM away from the AOI. We assumed that a total of 45 minutes would elapse from the time of the launch until an optimal search area is uploaded to the weapon and the weapon is launched.

1.9. Sensor to Shooter Results

In our simulation, we represented the weapon as a 22-knot radar searcher with a 3NM sweep width, simply because the present user interface does not permit entry of sweep widths less than one nautical mile. In the first demonstration, we used only one weapon and got a predicted effectiveness of .53.

The sequence of images in Figure 9 shows the target probability map progressing through the 75 minutes of the scenario, at fifteen-minute intervals. The rectangle in the final picture represents the search plan as calculated by the optimization algorithm.
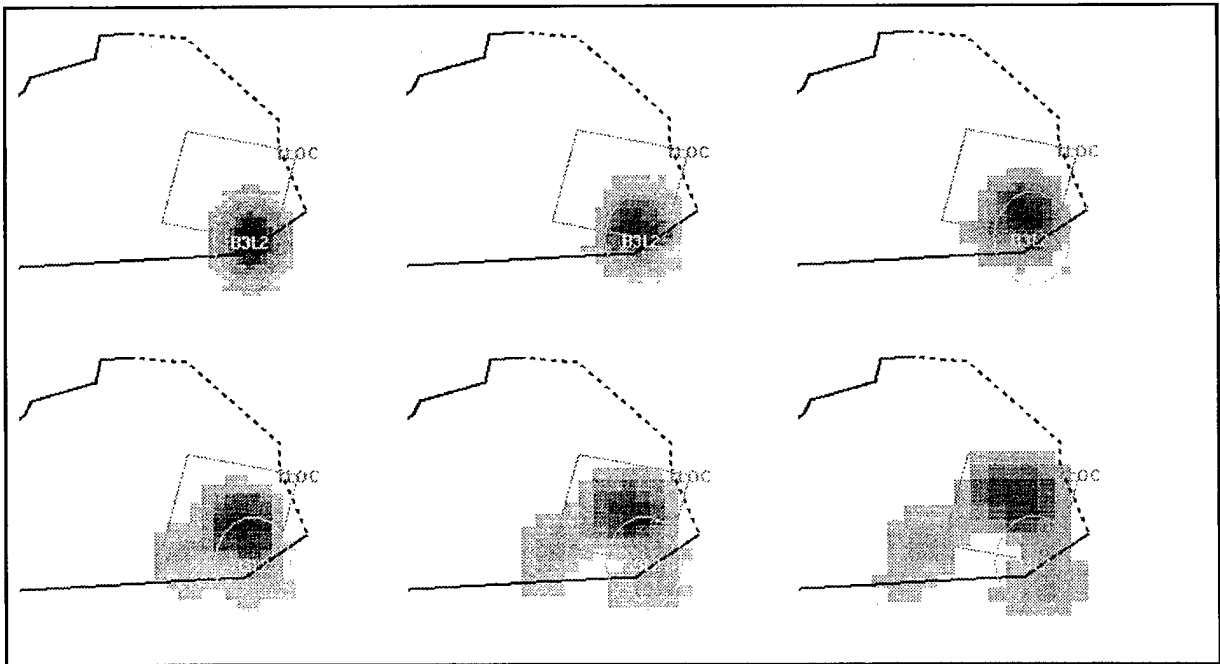
Figure 9.   LOCAAS Scenario – Single Weapon Launch

Next we ran a problem with four weapons launched at once and, as expected, obtained a very high probability of detection, about 0.89. The new pattern of search rectangles superimposed on the probability maps, is given in Figure 10.

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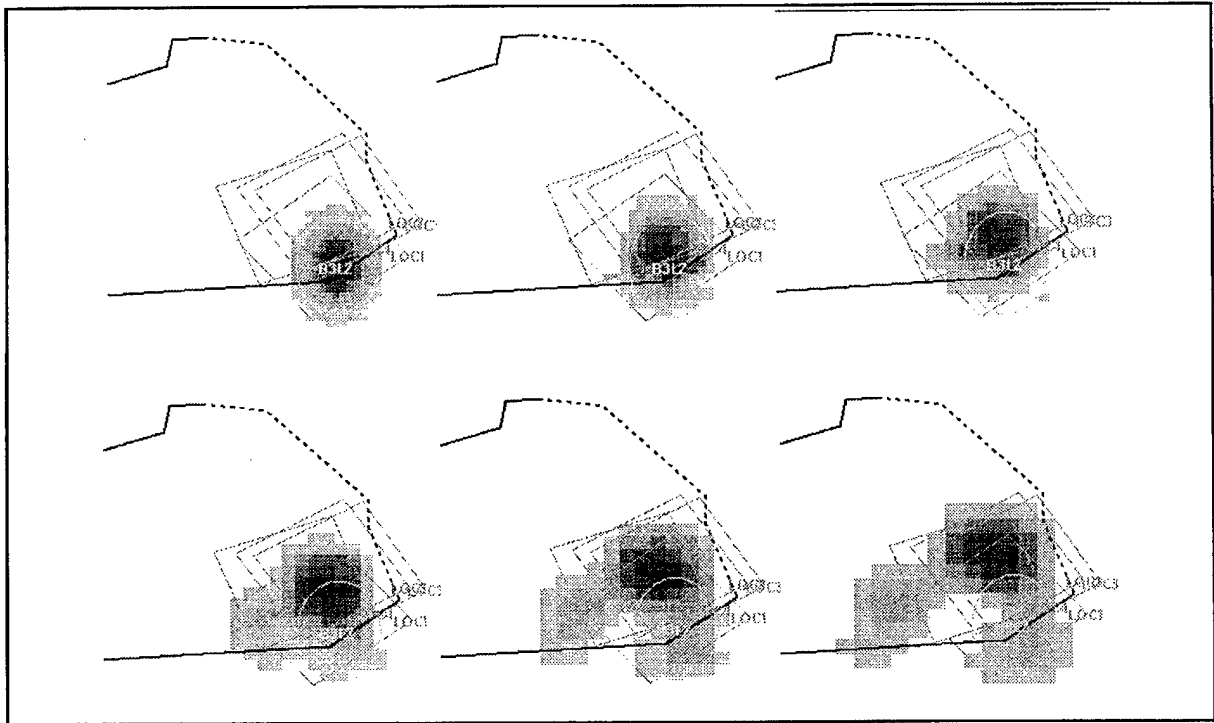
Figure 10. Search Areas for Four LOCAAS Weapons

1.10. Results and Conclusions of the Demonstration

This demonstration has pointed out some important considerations for a potential future implementation. First, the correlation of reports to model tracks in the planning system will require both an automated process and operator assistance to perform that task in a well-coordinated fashion.

Second, there is an enormous benefit in using a moving target optimizer, even as much as 24 hours into the future. The probability distributions we see in the first example do not converge to a stationary distribution, even at the far end of the planning period. This means that we must use a moving target optimizer in order to insure that the correct regions are searched at the correct time.

2. Environment

This ORDA decision aid needs to be provided to the command center having overall control of C4ISR assets in the theater of operations. While many workstations in the TBMCS could be used to host the application, the JSTARS Common Ground Station (CGS) might be a good place to start. The reason is that this workstation has the most up-to-date and dynamic picture of the battlefield, with the JSTARS MTI/SAR display. It would be simple to create a user interface that allowed an operator to select an MTI target and use that as a contact report for a specific target.

The probability map products produced by the JSTARS operator could then be exported to any other workstation in the center for the purpose of creating an optimal surveillance plan.

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3. Network

The AOC does not control resources at the detailed track level. Therefore any plan that originates there must be implemented by another command node that has such direct control. In the case of manned aircraft, the individual mission planning takes place at the squadron level, with each flight leader creating a detailed plan that meets the requirements of the mission. For UAVs, missions are also planned at the squadron, with the work done by the mission pilot before launch.

Most if not all mission planning is accomplished using some kind of computerized planning tool. In a network-centric environment, it would be most advantageous to have the AOC tool (ORDA) share its plans digitally with all the mission planning software packages to be used by the mission planners. We have discussed this idea with the developers of the mission planning module for the Global Hawk UAV program. They have a detailed mission planner that can create a flight path for that platform based on message inputs detailing the requirements described in several ways. First, the input can be a set of polygons setting out the area to be searched. Second, the requirement can be expressed as a set of collection points with priorities.

In Phase II, we could easily build the ORDA prototype so that it creates messages in the correct INTEL format, to serve as input to this mission planner. In this way, we could create an intelligent sensor-to-shooter stream, where *all* sensor and INTEL data is used to create a coordinated threat model (in ORDA) and then an optimal set of assignments are created automatically. In this prototype demonstration, the assignments can be immediately transmitted to the responsible command for execution, in a totally automated fashion.

We believe that this network demonstration will be one of the most valuable results of the Phase II process.

4. Other Decision Aids

Several auxiliary decision aids would be useful for operators in a center, given the availability of shared probability models for targets. We mention of few of these here.

4.1. Time of Arrival Decision Aid

Given a target model, an Area of Interest (AOI) can be represented temporarily as a search area with very high detection probability. If the program then computes the probability of detection for each target, by time period, this equates to the probability that the target has entered the area by that time. These results could be used to display a time-probability graph, or to automatically alert the operator when the probability exceeds a threshold value.

4.2. Area Coverage Decision Aid

The primary use of the Optimal Response Decision Aid will be just that, optimally responding to detected TCTs either immediately or over a period of time as in the examples here. On the other hand, if targets such as TCTs are suspected to be in an area but have not yet launched any missiles or otherwise been detected, it is still possible to create a decision aid that will create optimal surveillance plans. In fact, the ASUWTDA decision aid Wagner built for the U.S. Navy on a previous Phase II SBIR does just that. The operator enters the class of target, suspected locations from which targets may appear, zones to be kept clear, the targets' tactics, and the available surveillance flights. ASUWTDA then creates a full day's surveillance

plan for all the sorties and displays color-coded coverage maps. This decision aid is used daily on most Navy Battle Groups and Cruiser Destroyer Groups for their surveillance air plan.

4.3. Automatic Entry of Fused Target Reports

While the detection rate of TCTs is expected to be low and therefore manual assignment of detections to targets is possible, a better solution would be to have the assistance of a separate correlation decision aid to do these assignments automatically. The decision aid would need to have automatic inputs from various sources such as Joint STARS MTI, SIGINT sources, and operator input. It would operate independently of other fusion algorithms, except that if there were fusion results from any of the aforementioned sources, it would consider those results in its calculations.

4.4. Sensor Cueing Decision Aid

Once a probability map has been created, it could be very useful to use that map in conjunction with terrain, environment, and the projected path of a sensor, in order to cue the sensor for detection opportunities. This could be used for sensors of opportunity, where the Center does not have OPCON but where detection results could be obtained for a limited amount of data. Certain images from a high altitude UAV or surveillance satellite, for instance, could be automatically selected by this decision aid and then forwarded to the sensor control element.